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## FOREIGN TECHNOLOGY DIVISION



EFFECTS OF NUCLEAR EXPLOSIONS ON ELECTRONIC EQUIPMENT

by

Milan Vjestica



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## Effects of nuclear explosions on electronic equipment

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Electronic equipment is a very important and necessary part of modern military technology in all types of armed forces. The rapid increase in the quantities, types, and classes of electronic equipment has on the whole been accompanied by the increased susceptibility of armed forces to disturbances in the operation of electronic devices. Considering that a one-megaton nuclear explosion releases about  $10^{33}$  free electrons, which roughly corresponds to the total number of free electrons in the Earth's atmosphere, it must be concluded that in a possible war nuclear explosions (particularly high-altitude bursts) would have a significant and varied influence on the functioning of electronic devices.

An enormous amount of energy is released within a very short time (1 microsecond) after an explosion, resulting in great and rapid changes in the atmosphere, such as high pressures and temperature, ionizing radiation, and electromagnetic effects. Immediately after the explosion there are beta particles, X-rays and gamma

rays, and also neutrons of various energy levels, which contributes to the numerous and diverse effects of a nuclear explosion; some of these effects are seen on electronic equipment.

#### *Effects of shock wave*

An air or surface burst of a nuclear bomb produces a shock wave which propagates from the center of the explosion at 350 to 450 m/s and destroys all obstacles with its power. Proper placement can protect electronic devices from the blast, but because of the need to propagate electromagnetic waves, their antennas will be most exposed to the action of the shock wave; this is especially true of radio-relay, navigation, and radar antennas, which are erected at a prominent site for optimum performance.

#### *Effects of ionizing radiation*

The great number of electrons and gamma rays released, and also the enormous number of neutrons of various energy levels, have a complex influence on the operation and parameters of electronic devices. The elements of irradiated electronic devices change their character, while the free electrons and other products of the explosion create an ionized cloud at the site of the explosion; the cloud has a direct influence on the propagation of electromagnetic waves (attenuation, reflection, refraction).

*Changes in characteristics of materials.* The action of ionizing radiation on the elements of electronic devices leads to changes in the characteristics of the materials from which the devices are made, and thereby to changes in the parameters of the devices as a

whole. Variations in the characteristics of irradiated materials can be temporary or permanent. Temporary changes develop while a device is exposed to the ionizing radiation, but when the exposure ends the material regains its original characteristics. Permanent changes remain even when the material or element is no longer subjected to ionizing radiation.

An electronic device exposed to a lesser amount of radiation temporarily changes its performance, resulting in a brief interruption of operation. High-intensity radiation leads - because of permanent changes in material - to complete failure of the electronic device. Critical characteristics of electronic elements which change under the influence of ionizing radiation are given in table 1.

*Table 1*

elements	temporary change	permanent change
resistors	resistance, esp. in high-voltage resistors	resistance
capacitors	dielectric constant and losses in insulation	capacitance
electronic vacuum tubes	currents of individual electrodes	cathode emission, electrode currents, characteristics
gaseous tubes	firing potential	firing potential: anode-cathode, cathode-I grid; extinction potential: anode-cathode
semiconductor diodes	conduction current	characteristics
transistors	transistor current	amplification factor

Table 1 (cont.)

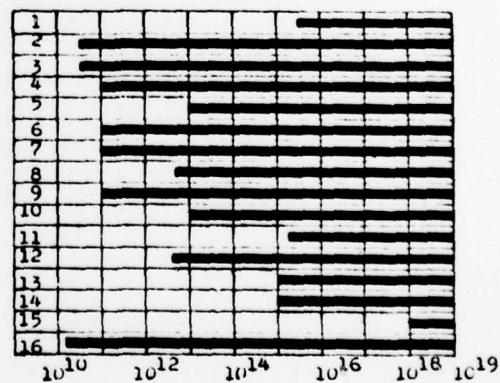
elements	temporary change	permanent change
photoresistors	"dark" resistance	sensitivity
photodiodes	"dark" current	sensitivity
combination elements	insulation resistance, electrical conductivity	insulation resistance, conductivity, contact resistance

Experimentation has confirmed that the change in the characteristics of electronic elements is dependent on the intensity of the ionizing radiation, i. e., on the flow of neutrons and gamma rays.

The results of tests in the 0.01-1 KT range are portrayed graphically in fig. 1 and 2. The onset of effects is represented by a bar which corresponds to the radiation dosage at which the first permanent changes in an electronic element are noted. Proper selection of the components of an electronic device can minimize its susceptibility to ionizing radiation.

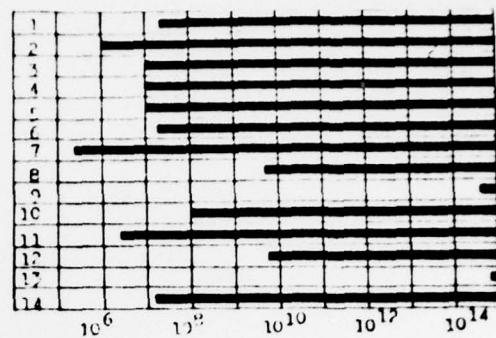
Fig. 1. Changes in properties of electronic elements as a function of neutron flow

1 - electronic tubes; 2 - semiconductor diodes; 3 - germanium diodes; 4 - silicon diodes; 5 - Zener diodes; 6 - transistors; 7 - LF germanium transistors; 8 - VF germanium transistors; 9 - NF silicon transistors; 10 - VF silicon transistors; 11 - resistors; 12 - rectifiers; 13 - magnetic materials; 14 - permalloy; 15 - transformer sheet; 16 - solar battery cells.



*Fig. 2. Changes in characteristics of materials and elements of electronic devices as a function of ionizing radiation dosage*

- 1 - phosphors; 2 - optical instruments and glass; 3 - elements of IC technology; 4 - photoelements;
- 5 - resistors; 6 - batteries;
- 7 - Teflon; 8 - polystyrene;
- 9 - ceramic; 10 - capacitors;
- 11 - tantalum capacitors; 12 - polystyrene capacitors; 13 - mica capacitors; 14 - electronic tubes.



*Effect on propagation of electromagnetic waves.* After a nuclear explosion X-rays and gamma-rays, neutrons, and beta particles ionize the atmosphere and cause attenuation, refraction, and reflection of electromagnetic waves which pass through the ionized region.

Of crucial influence is the action of the generated gamma shock, occurring in a period of 10 ns with energy of 1.5 MeV. The ionization of the air under the influence of the induced gamma radiation also leads to absorption of electromagnetic waves.

The fireball occurring after a nuclear explosion "muffles", as it were, electromagnetic waves, which are completely attenuated in passing through the center of the ball. The rising and expanding ball becomes "transparent" by means of the electromagnetic waves.

The coefficient of electromagnetic wave attenuation as a function of electron concentration in the atmosphere is given by the expression:

$$a = \frac{0.45 \cdot 10^{-3} \cdot n}{f^2} \quad (1)$$

where  $f$  - frequency in Hz;  $n$  - number of electrons per cubic meter  $e/m^3$ ;  $a$  - attenuation in db/km.

On the basis of expression 1 it is possible to calculate the electron concentration per cubic meter which is required for attenuation at frequency  $f$ .

The required number of electrons is given by the expression:

$$n = \frac{f^2 \cdot a}{0.45} \cdot 10^3 = 2.22 \cdot 10^3 \cdot a \cdot f^2$$

It is evident from expression 1 that attenuation will be less at higher frequencies, and thus the "opaqueness" of the ionized atmosphere for the shorter wavelengths does not last as long as the "opaqueness" for longer wavelengths.

The ionization effect also depends on the altitude of the nuclear explosion. At higher altitudes, where the air is thinner, the loss of energy is greater. At sea level the average life of free electrons is approximately one microsecond.

The ionization effect of nuclear explosions at altitudes below 15 km does not pose a serious threat to the propagation of electromagnetic waves. For directional and radar antennas whose wave path does not go above an altitude of 15 km, attenuation will not be serious. Marked disturbances will appear with antennas which use a component of a wave reflected from the ionosphere, which depends on the frequency and the concentration of electrons in the medium.

#### *Electromagnetic effects*

From the moment of a nuclear explosion until the decay of the fireball there are electromagnetic effects in the form of high-intensity electromagnetic pulses and electromagnetic radiation in a

wide range of frequencies. The electromagnetic effect appears in explosions up to an altitude of 16 km, generating a field with an intensity of up to 50,000 V/m, which is about a million times greater than for lightning. The greatest disturbances in electronic devices are caused by ionizing and electromagnetic effects.

At the moment of the explosion the large number of ions and electrons, moving with enormous velocity, generate electromagnetic pulses of considerable intensity and with a wide frequency range. The interference reaches the equipment through the antenna and (by induction) through cables, lines, and conductors.

Such conditions give rise to a powerful magnetic field, which changes the character of magnetic materials such as magnets, polarized relays, magnetic storage, and other elements.

Reception of the electromagnetic pulses through the antenna causes damage to the input circuits of electronic devices. The influence of the electromagnetic pulses on telephone lines and conductors is rendered through the induction of voltage from 10 to 50,000V and powerful currents which burn out line amplifiers, telephone exchanges, and terminal stations. The electromagnetic pulses last several milliseconds. Their components in the frequency range from 10 to 15 kHz penetrate up to 90 meters in the earth, with the effects reaching 50-300 km from the center of the explosion.

In sensitive receivers with high antennas (especially when directed towards the explosion) there is a degradation of sensitivity similar to wide-band noise interference. These disturbances last up to several minutes until the fireball cools and diffuses sufficiently.

A consequence of nuclear air bursts is synchrotron noise, caused by free electrons which spiral about the lines of a geomagnetic field and travel for a long time from the northern <sup>hemisphere</sup> to the southern until finally disappearing. The intensity of this noise decreases as the fourth power of the frequency and has radial direction. It does not have a decisive effect on the operation of electronic devices.

A nuclear explosion at an altitude of 300 km forms an envelope up to 100 km thick around the Earth where conditions, and therefore the operation of electronic devices, are quite different from other parts of the atmosphere.

By taking into account the power and type of a nuclear explosion and its distance from electronic devices, many undesirable effects can be alleviated, and a certain number can be completely avoided, if the configuration of terrain is used skillfully, the choice and direction of antennas are taken into account, and the necessary fortifications accomplished.

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